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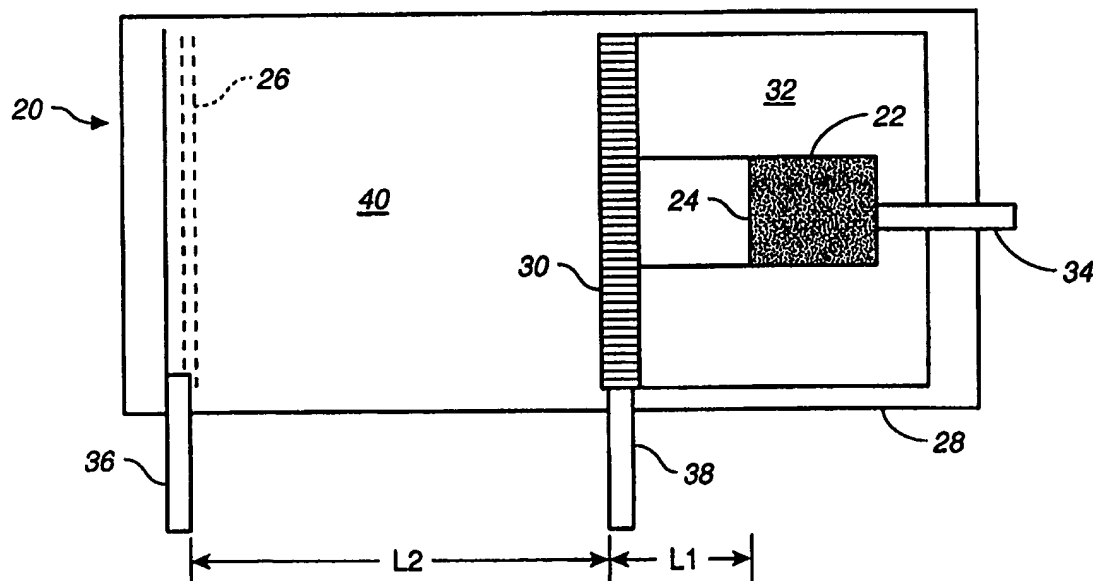
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(54) Title: FIELD EMISSION CATHODE FABRICATED FROM POROUS CARBON FOAM MATERIAL



(57) Abstract

A field emission cathode (20) is provided comprising an emissive member (22) formed of a porous foam carbon material. The emissive member has an emissive surface (24) defining a multiplicity of emissive edges.

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FIELD EMISSION CATHODE FABRICATED FROM
POROUS CARBON FOAM MATERIAL

FIELD OF THE INVENTION

This invention relates generally to field emission cathodes.

BACKGROUND OF THE INVENTION

Electron emission devices are key components of many modern technological products. For example, focused "beams" of electrons produced by such devices are used in X-ray equipment, high-vacuum gauges, televisions, large-area stadium-type displays, and electron beam analytical devices such as scanning electron microscopes.

Standard electron emission devices operate by drawing electrons from a cathode formed from a material that readily releases electrons when stimulated in a known manner. Typically, electrons are drawn from the cathode by the application of either a thermionic stimulus or an electric field to the cathode. Devices operating through application of an electric field are said to operate by field emission. Cathodes used in field emission devices are accordingly known as field emission cathodes, and are considered "cold" cathodes, as they do not require the use of a heat source to operate.

Field emission offers several advantages over thermionic stimulus in many electron emission applications. A field emission device (which creates an electric field) will typically require less power than a thermionic device (which creates a heat source) to produce the same emission current, respectively. Field emission sources are typically on the order of 1000 times brighter than comparable thermionic sources. The added brightness can be highly advantageous in lighting applications, such as stadium displays, or in applications which require the use of electron beams operating at intense focus, such as microscopes.

Further, the heat sources used in thermionic electron emission devices eventually damage them, leading to relatively quick "burnout." In applications requiring the use of many electron emission devices, such as in large area collective usage television screens, use of thermionic emission devices is very expensive because of the need to replace frequently devices suffering from rapid burnout.

Additionally, thermionic electron emission devices are not feasible for some applications. Thermionic devices are temperature dependent, and thus cannot be used in applications operating in extreme temperatures or where the ambient temperature

conditions vary substantially over time. For example, thermionic devices will not work properly in motors or engines where temperature conditions may swing from 70° Fahrenheit to -60° Fahrenheit within a few minutes. In contrast, field emission devices, which operate relatively independently from temperature conditions, can be used in such applications. Thermionic devices are also inappropriate for use where the heat used to draw the electron beam may damage the environment within which electron emission is to occur. For example, in X-ray applications focused near a human body, thermionic emission of electrons is undesirable as the heat source applied could cause pain or damage to the subject. Field emission devices avoid these concerns as they apply and generate relatively little heat.

Among various materials known to be suitable for the construction of field emission cathodes, carbon-based materials have proven to be capable of producing significant emission currents over a long lifetime in relatively low-vacuum environments (10^{-7} Torr or less). Carbon-based materials are particularly desirable for use in field emission because the products of chemical interaction between carbon and most common residual gases (such as oxygen and hydrogen) are non-condensable gases (such as carbon monoxide, carbon

dioxide and methane), which will not contaminate the surface of the field emission cathode.

Cathodes utilizing diamond films, bulk carbon, and graphite have been developed, but have required the application of substantial voltages to the cathode before generating significant electron emission. Other cathodes having regular, defined surface structures created from carbon materials include cathodes constructed from individual carbon fibers bundled together, cathodes machined from carbon rods, and matrix cathodes with carbon surfaces formed by photolithography and thermochemical etching procedures. While these cathodes can produce high current density upon application of low voltages, they are expensive to produce, as they require sophisticated fabrication procedures and/or manual assembly in their production.

It is an object of the current invention to provide an efficient and durable field emission cathode which may be manufactured simply and inexpensively.

Another object of the current invention is to provide a field emission cathode comprising an emissive member formed of a porous carbon foam material having an emissive surface which defines a multiplicity of emissive edges.

Other objects and advantages of the current invention will become apparent when the field emission cathode of the present invention is considered in conjunction with the accompanying drawings, specification, and claims.

SUMMARY OF THE INVENTION

A field emission cathode is provided comprising an emissive member formed of a porous carbon foam material. The emissive member has an emissive surface defining a multiplicity of emissive edges.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a scanning electron microscope's microphotograph of an emissive member of the present invention formed of Reticulated Vitreous Carbon™ and having a cut vertical edge.

Figure 2 shows an embodiment of a field emission device utilizing the inventive cathode.

Figure 3 is a perspective view of an inventive cathode having an emissive surface cut to form parallel rectangular grooves.

Figure 4 is a cross sectional side view of an inventive cathode within which a screw is embedded which serves as an electrical contact.

Figure 5 is a graph of the typical emission current/applied voltage characteristics of RVC cathodes tested at low to medium DC voltages.

Figure 6 is a cross sectional side view of an inventive cathode positioned within a nickel cap.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 illustrates a porous carbon foam material 10 used to form the emissive member of the inventive field-emission cathode. The member microphotographed is formed from Reticulated Vitreous Carbon™ ("RVC"). RVC forms vitreous (glassy) carbon into an open cell, reticulated structure having a random pore structure with good uniform pore distribution statistically. Typical characteristics of currently available porous carbon foam materials are listed in Table I.

**Table I: Characteristics of Currently Available
Porous Carbon Foam Materials**

Important Physical Characteristics	Typical Range of Values
Porosity Grade	10 to 100 pores per inch (ppi) with a potential additional compression by a factor of 10
High Surface Area	Up to 66 cm ² /cm ³ for 100 ppi
High Void Volume	90-97% for different porosity grades

Important Physical Characteristics	Typical Range of Values
Compressive Strength	40-170 psi (higher for compressed materials)
Tensile Strength	25-150 psi (higher for compressed materials)
Hardness	6-7 Mohs
Specific Resistivity	0.18-0.27 Ohm-in (0.47-0.69 Ohm-cm)

The emissive member of the inventive cathode is prepared by forming the porous carbon foam material into an emissive surface defining a multiplicity of emissive edges. The emissive edges constitute the broken edges 12 of individual pore structures 13 at the surface of the carbon material. These edges 12 can be produced in the emissive member according to various methods, including but not limited to conventional sawing and drilling of the carbon foam material, or precision milling techniques. Machine processing of the porous carbon foam material is preferred, as it forms well defined hard and sharp edges within the three-dimensional emissive member structure. The carbon foam material can be machined into the cathode's desired shape concurrently with the formation of the emissive surface. Figure 1 shows RVC material cut to form a three dimensional surface structure with a vertical edge 14.

In operation, electrons are drawn from the emissive edges 12 of the carbon foam material upon the

application of an electric field to the cathode. As the carbon foam material is porous, and does not have a continuous surface, each edge 12 is separate from each other edge 12, and an electric field applied to the carbon foam material will be enhanced about each edge 12, causing electron emission from the carbon material at the edge 12. By taking advantage of the random pore distribution of the porous carbon foam material, the invention avoids the labor and expense required to fabricate defined emission points on the cathode surface, while creating a carbon-based field emission cathode which operates well at low voltages and in low vacuum environments (10^{-7} Torr or less). RVC cathodes have been tested successfully in vacuum environments as low as 10^{-6} Torr.

The inventive cathode provides long-term stability in emission because of its use of large numbers of randomly distributed pore edges on the cathode's emissive surface. Cathodes employing defined emission tips carefully formed in regular patterns typically do not utilize extremely large numbers of emission tips, and can be devastated by the destruction of a few key emission sites. In contrast, as the inventive cathode forms vast numbers of emissive edges, the loss of a few emissive edges will have negligible impact upon the produced emission current. Further, in the inventive cathode,

destruction of an emissive edge frequently will create a new pore edge which will operate in place of the destroyed edge.

The current density available from the cathode can be controlled by changing the number of the emissive edges. This can be accomplished by varying the porosity of the carbon foam material: higher porosity grade materials will feature more pores 13 per inch ("ppi") and accordingly more edges 12 over the same surface area. Accordingly, the porosity of the carbon foam material used should be chosen according to the level of emission current density desired for the application in which the field emission device employing the inventive cathode is used. Lower limits on the porosity of the material are dictated essentially by the dropoff in the number of emission sites as the pore size of the material increases. Suitable porosities for RVC materials of the invention are equal to or greater than 50 ppi. Upper limits on the porosity of the material are governed by a current crowding effect: if the emissive edges of the emissive surface are too close to each other, the electrons will not release from each emissive edge, but will instead gather at a few emission sites, lowering the number of effective emissive edges and lowering the level of emission current density. RVC samples having a raw porosity of

100 ppi and undergoing 2x, 3x, 5x, and 10x compression have produced successful results in field emission applications in testing.

The shape of the emissive member of the cathode can also be chosen to meet the requirements of the desired application in which it is used. Shapes having a large, flat emissive area from which a substantial emission current can be drawn will be suitable for many applications, such as lighting displays. Appropriate shapes for the inventive cathode include, but are not limited to, discs, cubes, cylinders, rods, and parallelipeds.

RVC is a preferred porous carbon foam material due to characteristics it possesses which are desirable in field emission. RVC has a high void volume (up to 97%) and large surface area (up to 66 cm²/cm³ for 100 ppi) which creates a large number of emissive edges on its emissive surface. Further, RVC features a highly uniform micromorphology. As a glassy material, RVC has greater internal uniformity of its pore structures than do natural graphites. Accordingly, emission current drawn from an RVC emission surface has a more uniform distribution than would a natural graphite material.

RVC is also characterized by exceptional chemical inertness and oxidation resistance. These properties reduce the hazard of chemical reactions between ions

or molecules of residual gases with the cathode surface, which can be a critical factor when the field emission cathode is used in modest vacuum environments. RVC's hardness, rigid volume structure, and high compression strength provide durability and allow the material to be easily machined to desired shapes. Its high tensile strength resists ponderomotive forces created by strong electric fields which act to apply pulling action to the cathode structure and create tension in the material. Further, RVC has a fairly high resistivity for a carbon material (0.18-0.27 Ohm-in for RVC as compared to 0.001-0.002 Ohm-in for solid vitreous carbon), which limits localized currents and thus reduces the probability that surface arc currents will form. This increases the lifetime of the cathode.

RVC typically is formed by high-temperature pyrolysis under a controlled atmosphere from a raw polymeric resin. RVC is presently commercially available from Energy Research and Generation, Inc. ("ERG") of Oakland, California. Destech Corporation of Tucson, Arizona also sells an open-celled glassy carbon foam.

It should be understood, however, that the porous carbon foam material used to form the inventive cathode need not be RVC or be manufactured according to any specific method. The invention is directed

toward using the surface morphology of a porous carbon material to form a large number of edges acting as individual emission sites. The material should have a sufficiently low porosity such that current crowding does not occur, but a sufficiently high porosity such that a significant emission current is reliably produced by the cathode. The inertness and oxidation resistance of the material should be adequate to prevent chemical reaction hazards. The material should be durable and should have sufficient tensile strength to resist ponderomotive forces created within the cathode structure. Its resistivity should be high enough that significant surface arc currents will not form during operation of the field emission device in which the cathode is used. The inventive cathode can use any porous carbon foam material, produced according to any method, that has the characteristics described above.

The inventive cathode can be used in any field emission device application. Figure 2 depicts an example of a simple field emission device 20 in which the inventive cathode could be used. An inventive cathode 22, having emissive surface 24, and anode 26 are enclosed within a vacuum envelope 28 operating at a sufficiently high vacuum that avoids undesirable chemical reactions with residual gases upon stimulation of electron emission. A gate 30 is

positioned between cathode 22 and anode 26 such that the emissive surface 24 of cathode 22 is separated from gate 30 by a distance L1, and gate 30 is separated from anode 26 by a distance L2. Cathode 22 is preferably set within an insulating member 32 such that insulating member 32 does not obstruct paths between emissive surface 24 and gate 30. Insulating member 32 acts to electrically isolate gate 30 from cathode 22 while assembling gate 30 and cathode 22 into one structure, assuring maintenance of the proper distance L1. A cathode contact 34, anode contact 36, and gate contact 38 are positioned in contact with cathode 22, anode 26, and gate 30, respectively, and extend through vacuum envelope 28 such that voltage differentials can be applied between cathode 22, anode 26, and gate 30 by connecting a means for creating a voltage differential (not shown) across the contacts.

In operation, a first voltage differential is applied between cathode 22 and anode 26, creating an electric field between cathode 22 and anode 26 which tends to pull electrons from the surface of cathode 22 and towards anode 26 through vacuum environment 40, but produces insignificant emission current when applied independently. When emission is desired, a second voltage differential of the same polarity as the first voltage differential is applied between cathode 22 and gate 30, enhancing the electric field

sufficiently to produce the desired emission current. Use of gate 30 in this manner is desirable as the level of emission current produced by field emission device 20 can be controlled by altering the second voltage differential in small increments. Both voltage differentials may be created by grounding cathode 22 and applying positive voltages to gate 30 and anode 26, but it should be understood that other means of creating both voltage differentials may be employed. Distances L1 and L2 and the first and second voltage differentials should be chosen to meet the requirements of the specific application to which the field emission device 20 is oriented while producing the emission effects described above.

The simple field emission device 20 described above is configured suitably to act as a cathodoluminescent light source and can be constructed from materials typically used in cathode ray tube type devices. For example, vacuum envelope 28 may be a glass envelope, while gate 30 may be a mesh hanging on a frame supported by ceramic insulators 32. Materials suitable for constructing gate 30 include, but are not limited to low vapor pressure refractory metals such as platinum, gold, molybdenum, nickel, or nichrome, and conductive non-metals such as carbon mesh.

It should be understood that the inventive cathode can be used in a wide variety of field

emission applications and its use is not limited to field emission device 20. Potential applications in which the inventive cathode could be used include, but are not limited to, large area stadium-type displays, X-ray sources (which could potentially be used in vitro), high-vacuum gauges, flat panel displays, digital or pictorial indicators, backlights for LCD displays, UHV devices such as clystodes or magnetrons, analytical tools such as scanning electron microscopes, and microfabrication tools such as electron beam evaporators or heaters.

Experimental Results

Several configurations of reticulated vitreous carbon field emitters have been tested. The tested RVC cathodes were prepared from bulk RVC material and shaped by cutting the RVC material manually with a knife or razor blade or by machining. A number of simple RVC cathode shapes were tested, including cylinders having a diameter of approximately 3 millimeters, pyramids, and cubes and rectangular blocks having sides ranging in length from between 3 to 5 millimeters.

An emission surface for each RVC cathode was formed during the cutting or machining of each RVC cathode. For some of the tested RVC cathodes, the emission surface was made planar. Referring to Figure 3, the other tested RVC cathodes were cut or machined

to produce a three-dimensional emission surface 100 formed by cutting parallel rectangular grooves 102 into the emission surface. During testing, the RVC cathodes having a three-dimensional emission surface such as that shown in Figure 3 generally produced larger emission currents when the same voltage was applied than the cathodes having a planar emission surface.

Each tested RVC cathode was provided with a contact in the form of a screw or a smooth flexible wire formed from stainless steel or molybdenum. Referring to Figure 4, the screw 104 or flexible wire was dipped at one end into a preparation of colloidal graphite and isopropanol, such as Electrodag™ or Aquadag™, both of which are manufactured by the Acheson Colloids Company of Port Huron, Michigan. The dipped end of the screw or wire was then screwed or pushed into the side 106 of the RVC cathode 108 opposing the cathode's emission surface 100 until the screw or wire was embedded in the cathode to a depth d_1 of two to four millimeters. The colloidal graphite preparation, which served as an adhesive, was allowed to dry in air without baking for three to four hours in some of the tested RVC cathodes. Other tested RVC cathodes were baked at temperatures between 150 to 200 degrees Centigrade for up to one half hour to dry the colloidal graphite preparation. Whether baked or air

an anode was positioned within the vacuum chamber at a distance of two to five millimeters from the cathode. Three types of phosphor screens were tested as anodes. The first type of phosphor screen was formed by depositing P-22 field emission phosphors upon a metal disk. The second type of phosphor screen was formed by depositing P-22 field emission phosphors upon a glass disk coated with indium tin oxide ("ITO"). The third type of phosphor screen was formed by depositing P-22 field emission phosphors upon a glass disk, and subsequently aluminizing the rear side of the glass disk, over the deposited phosphors. P-22 field emission phosphors are available from Osram Sylvania of Towanda, Pennsylvania.

In the triode configurations, the anode was positioned within the vacuum chamber at a distance of two to five centimeters from the cathode, and a stainless steel modulator grid was positioned between the RVC cathode and the anode. The modulator grid served the same purpose as the gate 30 discussed with regard to the field emission device 20 of Figure 2. While decreasing the distance between the modulator grid and the RVC cathode decreases the level of voltage which must be applied to the gate to stimulate emission from the RVC cathode, placing the gate too close to the cathode can short out the cathode due to the flexibility of the modulator grid. The testing

indicated that spacing the stainless steel modulator grid at a distance of one-tenth of a millimeter to one millimeter from the RVC cathode worked well.

During both the diode and triode configuration testing, the vacuum chamber was pumped to a pressure of between 10^{-6} to 10^{-9} Torr. Two voltage schemes were used. In the first scheme, the RVC cathodes were kept at ground potential while a high positive voltage was applied to the anode, if in diode configuration, or to the modulator grid, if in triode configuration. In the second scheme, a high negative voltage was applied to the RVC cathodes while the anode was kept at ground potential, if in diode configuration, or the modulator grid was kept at ground potential, if in triode configuration. In the low to medium voltage testing, voltage was applied in DC mode.

Figure 5 shows the emission current/applied voltage characteristics of the RVC cathodes tested in diode configuration at low to medium DC voltages. Line A indicates the emission current per applied voltage produced upon the initial application of voltage, while line B indicates the emission current per applied voltage produced after voltage had been applied for over 30 minutes.

During testing, most of the RVC cathodes produced an unstable emission current upon the initial application of voltage, which was characterized by a

series of spikes in the emission current, as shown in line A of Figure 5. The field emission pattern visible on the phosphor screen (the anode) corresponded to the variations in the emission current. The period of instability of the emission current varied between the tested RVC cathodes from a few minutes to approximately two hours. After the period of instability, the emission current stabilized such that it fluctuated from between ten to twenty percent of an average value. Those fluctuations remained present for the remainder of the tested lifetime of the cathodes. Ballast resistors having resistances in the range of between 10 and 500 megaohms were added in series to the cathode, the anode, or both the cathode and the anode during testing to reduce the magnitude of the fluctuations.

The period of instability, which has been termed the "training" of the emission current, is believed to result from (i) the desorption of contaminants initially present on the emission surface of the RVC cathode and (ii) by the destruction of the sharpest emissive edges of the RVC material. After the contaminants are desorbed and the sharpest emissive edges are destroyed, the current becomes more uniformly distributed over the multitude of emission sites present on the emissive surface of the cathode. The ten to twenty percent fluctuations in the emission

current present after the training period may result from the statistical equilibrium of the destruction of emission sites on the emission surface and the production of new emission sites as destruction produces new emissive edges, resulting in a constant redistribution of the net emission current over the multitude of emission sites.

RVC cathodes can be cut from bulk RVC material using laser cutting. RVC cathodes prepared by laser cutting may have a shorter training period before the emission current stabilizes, as laser cutting may introduce fewer contaminants to the emission surface and produce an emission surface having emissive edges which are more uniform than those formed from manual cutting or machining.

High Voltage Tests and Beam Focusing

Six RVC cathodes were tested at high voltage. Those cathodes were formed from bulk RVC materials, and had porosities between 50 and 100 ppi, or were formed from 100 ppi RVC material which was compressed by a factor of two to ten times. The RVC cathodes were each placed in a stainless steel high vacuum chamber equipped with an ion or turbo pump capable of reducing the pressure within the vacuum chamber to 10^{-9} Torr. No insulative material was used to encapsulate the RVC cathode. An anode was positioned from 8 to 15 centimeters away from the RVC cathode. The anode was

formed from a round metal plate having a fifteen centimeter diameter which was coated with P-22 field emission phosphors.

During testing, the vacuum chamber was pumped to a base pressure of approximately 5×10^{-8} Torr. Negative voltages of up to 55 kV were applied to the RVC cathode, while the anode was maintained at ground potential. The negative voltages were applied both in pulsed and in DC mode. The production of emission current resulted in significant outgassing of the anode, resulting in an overall vacuum chamber pressure of approximately 10^{-6} Torr. The stainless steel vacuum chamber was surrounded by lead plates during operation because of the risk of X-ray generation, and a portable X-ray sensor was used to continuously monitor the x-ray level outside the lead plates.

All six samples produced emission currents of up to 10 mA which were stable (fluctuating within 10-20% of an average value) over observation periods of between two and four hours. However, the beam spread of the emitted electron beam was sufficiently large that the beam spot exceeded the diameter of the anode, such that part of the electron beam was captured by the walls of the vacuum chamber.

Referring to Figure 6, tests were conducted in which the beam spread was significantly reduced by positioning the RVC cathodes within a cap 110. Caps

110 formed from nickel and caps formed from stainless steel were tested. The emission surface 100 of the RVC cathode was recessed within the cap 110 at a distance from the front edge 112 of the cap 110 of approximately 4 millimeters. However, the use of the cap 110 made it necessary to increase the negative voltage applied to the cathode to produce the same average emission current. For example, a voltage of -55 kV applied to the RVC cathodes when placed in a cap 110 at 4 millimeters from the cap's front edge produced the same average emission current as a voltage of -37 kV applied to the RVC cathodes without the cap 110.

Although the foregoing invention has been described in some detail by way of illustration for purposes of clarity of understanding, it will be readily apparent to those of ordinary skill in the art in light of the teachings of this invention that certain changes and modifications may be made thereto without departing from the spirit or scope of the appended claims.

IT IS CLAIMED:

1. A field emission cathode, comprising:
an emissive member formed of a porous carbon foam material, said emissive member having an emissive surface defining a multiplicity of emissive edges.
2. The field emission cathode of claim 1 wherein said emissive member contains a multiplicity of pores, said emissive edges projecting from said pores at said emissive surface.
3. The field emission cathode of claim 2 wherein said porous foam carbon material has a porosity, said porosity greater than or equal to 50 pores per inch.
4. The field emission cathode of claim 3 wherein said porosity of said porous carbon foam material is less than or equal to 1000 pores per inch.
5. The field emission cathode of claim 4 wherein said porous carbon foam material has a void volume in the range of between 90 and 97 percent.
6. The field emission cathode of claim 5 wherein said porous carbon foam material has a

compressive strength of at least forty pounds per square inch.

7. The field emission cathode of claim 6 wherein said porous carbon foam material has a tensile strength of at least 25 pounds per square inch.

8. The field emission cathode of claim 7 wherein said porous carbon foam material has a hardness of at least six Mohs.

9. The field emission cathode of claim 8 wherein said porous carbon foam material has a specific resistivity in the range of between 0.18 and 0.27 Ohms per square inch.

10. The field emission cathode of claim 9 wherein said porous carbon foam material is Reticulated Vitreous Carbon™.

11. A field emission device, comprising:

a cathode formed of a porous carbon foam material, said cathode having an emissive surface defining a multiplicity of emissive edges;

5 an anode;

a vacuum environment enclosing said cathode and said anode; and

means for maintaining said cathode and said anode
at a voltage differential such that a plurality of
10 electrons are emitted from said emissive edges of said
cathode towards said anode.

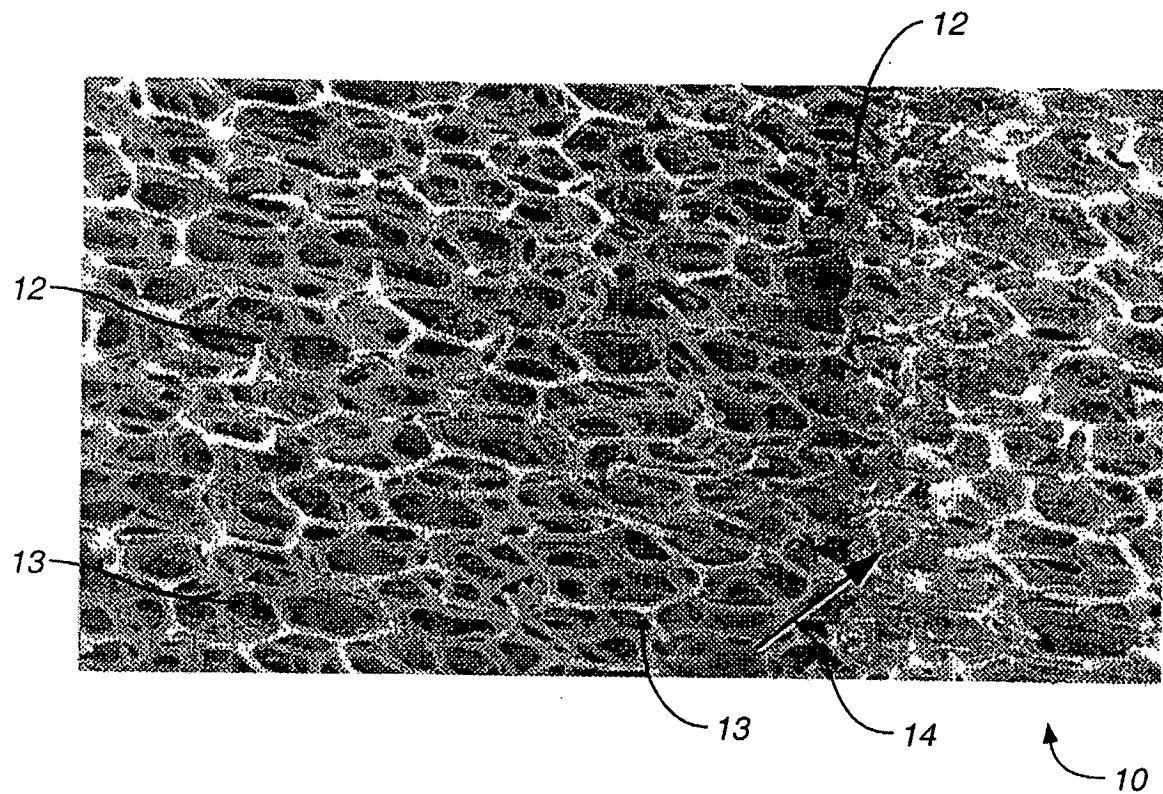
12. The field emission device of claim 11
further comprising a cap within said vacuum
environment, said cap having a front edge, said
cathode positioned within said cap such that said
5 emissive surface of said cathode is recessed from said
front edge of said cap.

13. The field emission device of claim 12
wherein said cap is formed from nickel.

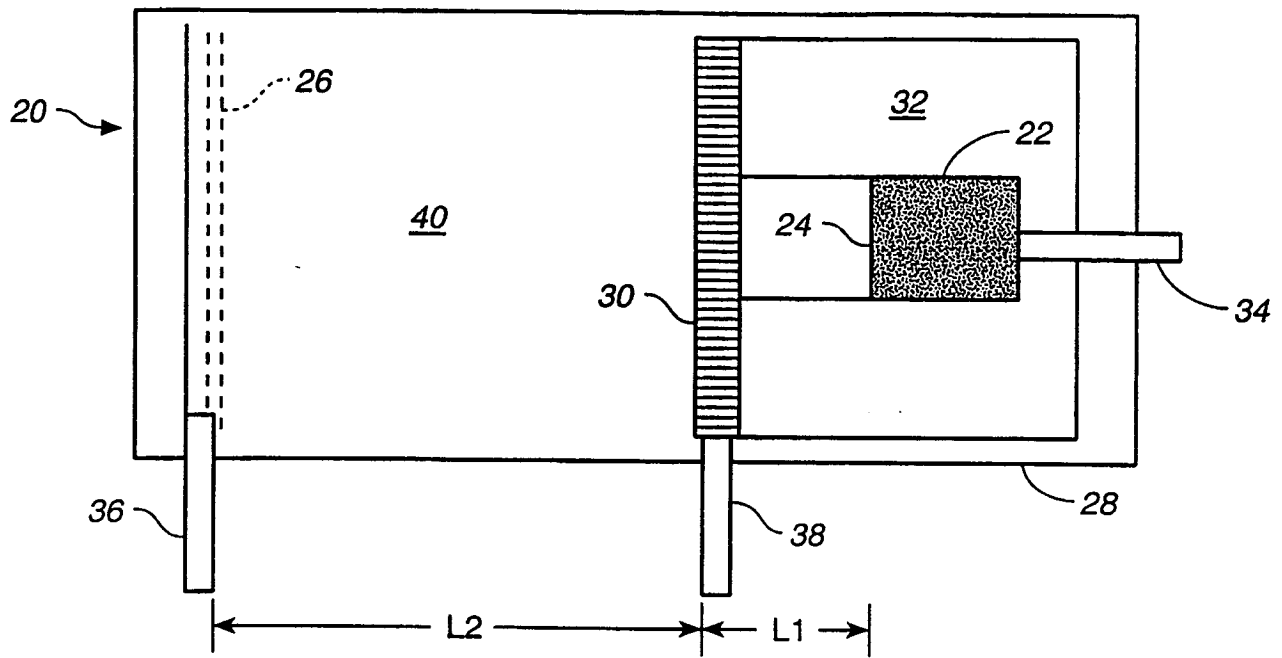
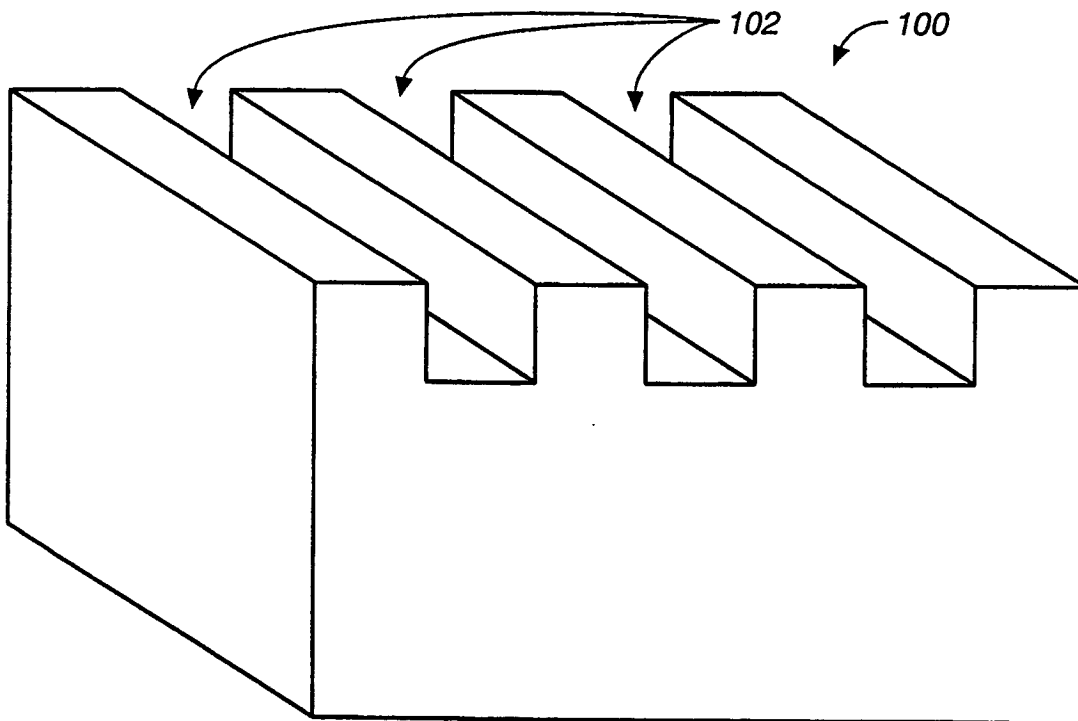
14. The field emission device of claim 12
wherein said cap is formed from stainless steel.

15. The field emission device of claim 12,
wherein said emissive surface of said cathode defines
a series of parallel rectangular grooves in said
porous carbon foam material.

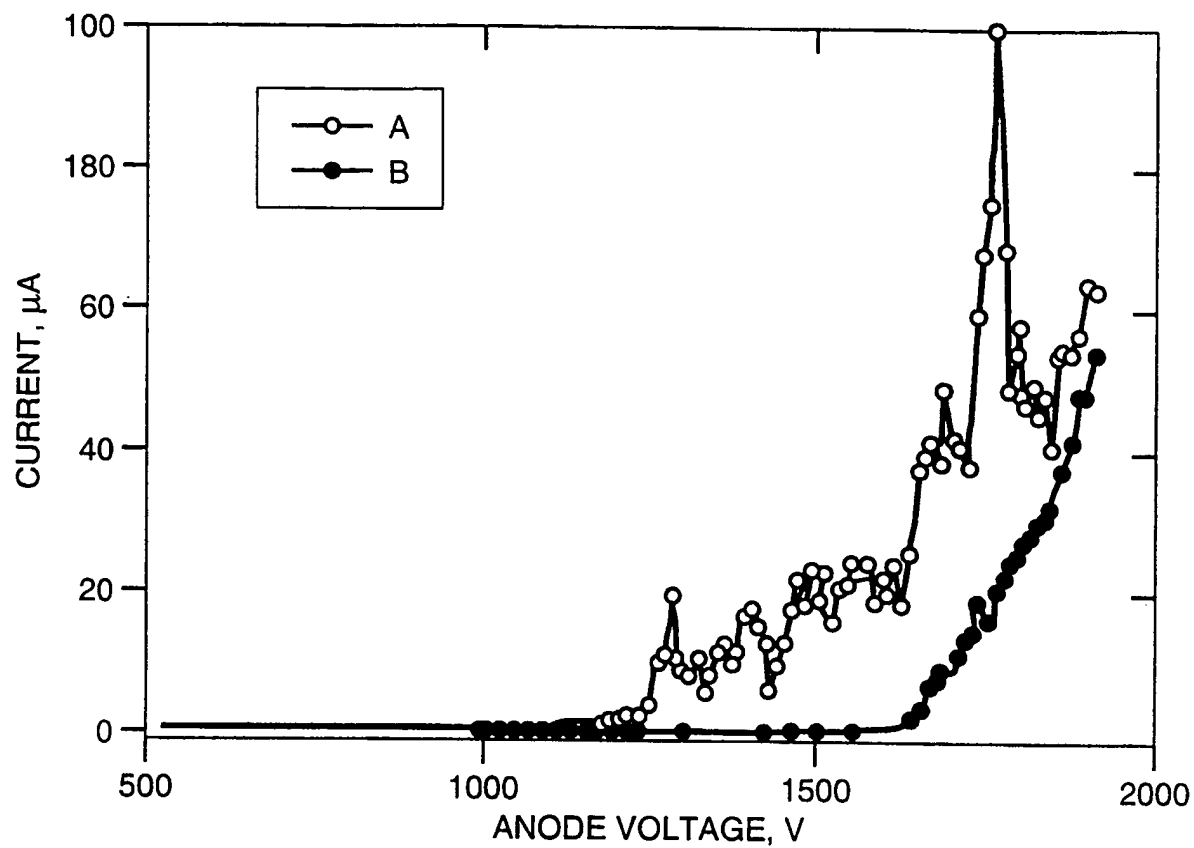
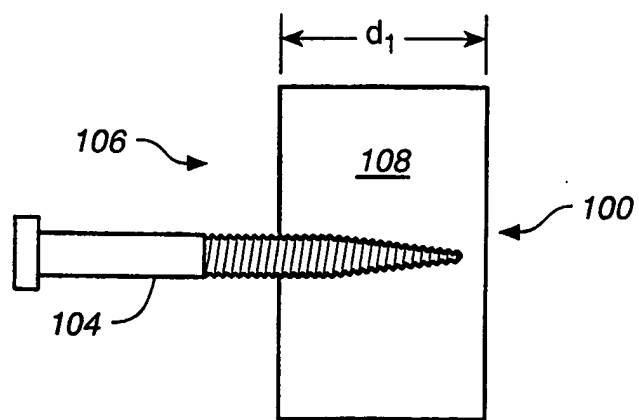
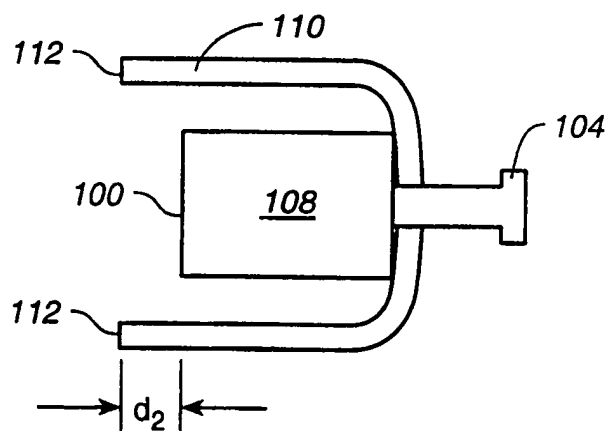
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**FIG._1**

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**FIG. 2****FIG. 3**

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**FIG._5****FIG._4****FIG._6**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/04427

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C25B 3/00; H01J 1/30

US CL : 313/311, 310, 346 R, 346 DC; 204/59 R

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 313/311, 310; 204/59 R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,673,473 A (Ang et al.) 16 June 1987 (16.6.87), entire document	1-11
Y		12-15
Y	US 5,594,299 A (Bossert et al.) 14 January 1997 (14.1.97) col.3, lines 24-34	12
Y	US 5,548,184 A (Choi et al.) 20 August 1996 (20.08.96), entire document	13,14
Y	US 5,072,148 (Grunwald et al.) 10 December 1991 (10.12.91), entire document	15

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

13 APRIL 1999

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